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THEORY OF JOSEPHSON JUNCTION MIXERS.

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ABSTRACT:

A mathematical analysis of the rf irradiated Josephson junction has shown that an external load at the rf frequency is transformed into a parametric small signal Josepson junction seen at dc as a subharmonic step in the U-I caharacteristic. This model is used to investigate the properties of Josephson junction mixers.

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In a publication by the same author (to be published) it has been shown that a resistively shunted ideal Josephson junction (with shunt resistance R and critical current i_c) which is rf and dc current biased has an rf voltage component at the local oscillator frequency of

$$u_1 = \frac{a_1 \phi_o \omega_{rf}}{2\pi} \cos(\omega_{rf} t + \frac{4\pi}{\phi_o} \int u_o dt + 2\varphi) \qquad (1)$$

where u_o is the small signal dc voltage, defined as the difference between the junction voltage and that at the point halfways between the zeroeth and the first constant voltage step.

It has furthermore been shown that if a small signal current is coupled to the biased junction it will cause u_o to change with the amount

$$u_o = r_o(i_o + \sum \beta_n i_n + \cos\varphi \sum \beta_{n/2} i_{n/2}) \qquad (2)$$

In this equation i_n stands for the amplitude of a current at frequency $n\omega_{rf}$ with the same phase as the local oscillator; $i_{n/2}$ has a similar definition. The coefficients a_1, r_o, and β_n have been calculated by computer for typical biasing conditions by the author.

If the junction is loaded by a conductance G_1 at the local oscillator frequency, for instance by the generator impedance of the signal source, a

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current $-u_1G_1$ will flow which has a component in phase with the local oscillator that is equal to $-G_1a_1\phi_0(\omega_{rf}/2\pi)\cos[(4\pi/\phi_0)\,u_1dt + 2\varphi]$. Inserting this into Eq.2 we obtain

$$\frac{u_o}{r_o} + G_1a_1\beta_1\phi_o(\omega_{rf}/2\pi)\cos[(4\pi/\phi_o)\int u_1dt + 2\varphi] = i_o + \sum\beta_n i_n + $$
$$+ \cos\varphi\sum\beta_{n/2}i_{n/2}. \qquad (3)$$

This has the same form as the equation of a Josephson junction with critical current $G_1a_1\beta_1\phi_o\omega_{rf}/2\pi$, in parallel with a resistance r_o and driven by the downconverted currents on the righthand side of the equation. It can be called a parametric Josepson junction because its critical current is proportional to G_1. It shows up in the dc voltage-current characteristics as a half-harmonic constant voltage step with a length equal to twice the parametric critical current.

For small dirving currents a Josephson junction looks like an inductance; this is also true for the parametric one. The value of this parametric inductance is

$$L_{par} = (2G_1a_1\beta_1\omega_{rf})^{-1} \qquad (4)$$

It has the effect of shorting the signal at the intermediate frequency in a mixer. It can, however, be tuned out with a capacitor: This is equivalent to placing the intermediate frequency equal to the plasma frequency of the parametric Josephson junction. If we do this we find that all the downconverted signal current is forced through the if load G_{if}, provided that $G_{if} \gg r_o^{-1}$, which condition is usually fulfilled. The power gain of the mixer will then become

$$PG = 4\beta_1^2\frac{G_{if}}{G_1}\ . \qquad (5)$$

As β_1 is close to one we can easily make $PG > 1$. The parametric inductance can obviously be tuned out only in a limited bandwidth which is given by

$$\Delta\omega_{if}/\omega_{if} = 2a_1\beta_1\frac{\omega_{if}G_{if}}{\omega_{rf}G_1} \qquad (6)$$

The intrinsic noise of the junction is caused by downconverison of thermal noise emanating from the shunt resistance R. Once the β_n:s and $\beta_{n/2}$:s are known the midband noise temperature can easily be computed for each case, always assuming that the currents are small enough that the junction keeps phase-locked to the local oscillator. For a fixed ratio between G_{if} and G_l, i.e. a fixed gain and bandwidth, we find that the noise temperature will be inversely proportional to $G_{if}R$. There is thus no intrinsic lower limit. With a judicious choice of circuit parameters it should, in fact, be possible to reach lower noise temperatures than what has so far been thought possible.